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# MODELING THE IMPACT OF $SO_2$ POLLUTION ON THE COMMUNITY STRUCTURE AND SUCCESSION IN A CONIFEROUS FOREST OF THE WESTERN U.S.A.

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MODELING THE IMPACT OF $SO_2$ POLLUTION ON THE COMMUNITY STRUCTURE AND SUCCESSION IN A CONIFEROUS FOREST OF THE WESTERN U.S.A.+

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We are developing a model to project the future impact of $SO_2$ pollution on western U.S.A. forests. For a case study, the model is being applied to the Ponderosa Pine (Pinus ponderosa) and mixed conifer forests of the Sierra Nevada mountains of California, U.S.A. The associated species in these forests are Abies concolor (white fir), Pseudotsuga menziesii (Douglas-fir), Pinus lambertiana (sugar pine), Libocedrus decurrens (incense-cedar), Quercus kelloggii (California black oak), and Pinus jeffreyi (Jeffrey pine). The model is based on JABOWA[1], a simulator of forests of the northeastern U.S.A. For use in western forests, extensive modifications are needed in JABOWA in temporal seed-crop patterns and by introducing fire ecology and moisture stress on vegetation.

The model establishes individual seedlings, grows them individually, and simulates mortality of each one. Growth occurs on a forest stand of area specified by the user. An area of 400 $m^2$ is typical. The structure of the computer code is shown in Figure 1. Control in MAIN follows the arcing arrow counterclockwise. Biological and environmental parameters are read in by TREEDTA and SITEDTA, respectively. SITE calculates stand characteristics such as actual and potential evapotranspiration and growing degree-days. START sets the initial number and sizes of all trees. CYCLES generates a table of the good and bad seed crop years for each species using a Bernoulli random process algorithm. RINGS generates a list of the years with fire. POLLUTE calculates the effects of $SO_2$ pollution on growth. BIRTH determines numbers of seedlings established each year; GROW calculates growth in diameter at breast height (dbh) and height of each tree; FIRE calculates fire intensity and damage; and KILL causes tree death based on ecological risk, lack of growth, and fire damage. MAIN calls BIRTH, GROW, FIRE, and KILL each year for the number of years of simulation. SHADE calculates leaf area index of leaves shading each tree; FUEL calculates moisture content of forest-fire fuels; BRUSH calculates dynamics of live fuel; LOAD calculates dynamics of forest litter; FIREMOD[2] calculates fire intensity. INJURY calculates height of crown scorch, and RISK calculates probability of mortality.

FIREMOD calculates fire intensity in kilowatts/meter of fireline length as a function of fuel loading (kg/$m^2$), windspeed (km/hr), fractional moisture content of fuel, and other environmental variables associated with the site. This calculation is based on the work of Rothermal[3]. Then using the work of Van Wagner[4], the height of crown scorch is calculated as a function of fire intensity, windspeed, and ambient temperature. Probability of tree mortality is modeled by Bevins[5] as a function of tree diameter, bark thickness, and height of crown scorch.

Figure 2 shows the response of _P. ponderosa_ and _A. concolor_ with and without fire. The dark, solid line is the response when fires are allowed to occur at their natural frequency. The light, dotted line is the response when fires are suppressed. These lines are the basal area averaged over 25 computer runs. The noise in the figures result from the stochastic nature of the death of large trees. _P. ponderosa_ is considered to be a fire climax species. If the simulation were allowed to run for longer times, _A. concolor_ would eventually achieve dominance in the absence of fire. However, fire suppresses the fir in favor of the pine. Note the behavior of both trees before 250 years compared to after 250 years.

At levels of $SO_2$ that exceed the damage threshold, $SO_2$ affects seed crops, foliage, growth, and ultimately mortality. To examine the effects of pollution, consider the minimally significant case of 10% growth reduction of the dominant species _P. ponderosa_. We scale the response of the remaining species according to their relative sensitivities as reviewed by Davis and Wilhour[6] and the dose-response functions determined by Temple[7] for four urban trees. We estimate growth reduction for each species taking into account the residence time of needles and assuming a similar dose response for all species in the same sensitivity category. We note that Scheffer and Hedgcock[8] estimated the annual dbh increment of P. ponderosa to be reduced by 42% in 1930 when the seasonal average of $SO_2$ was 0.05 ppm near the smelter at Trail, B.C., Canada.

We have two alternative pollutant effect submodels incorporated in our model, one based on the seasonal average $SO_2$ concentration and the other on successive pollutant episodes. We ran the seasonal average model at the $SO_2$ level which produces the 10% growth reduction of P. ponderosa.

In Figure 3, the basal area of P. ponderosa, A. concolor, and Pseudotsuga menziesii in the absence of pollution is shown by the dark, solid line and in the presence of pollution by the light, dotted line. The basal area of P. ponderosa is significantly reduced by pollution. A. concolor is enhanced in basal area. This enhancement results from the reduced competition from P. ponderosa and because A. concolor is relatively $SO_2$-tolerant. Each A. concolor tree suffers only a 1 to 2% growth reduction from $SO_2$. This reduction is more than compensated by the reduced vigor of P. ponderosa which results in less competition to A. concolor. Note that the growth of Pseudotsuga is extremely reduced. This is a poor site for Pseudotsuga even in the absence of $SO_2$. The competitive disadvantage of Pseudotsuga is made worse by the pollution because Pseudotsuga is sensitive to $SO_2$ and carries its needles for seven years compared to three years for P. ponderosa. The effects on growth reduction for the individual tree are estimated to be 18% compared to 10% for P. ponderosa. This 18% tree growth reduction translates into a much larger effect on basal area due to the competitive interactions contained in the model.

The graphs in Figure 3 are summarized by the box plots in Figure 4. The horizontal line near the middle of the box is the median during 500 years. The range is given by the vertical line. Note that the median of P. ponderosa decreased 18% with the $SO_2$ treatment; the median of A. concolor increased 26%; and Pseudotsuga decreased 83%. This compared with the individual tree growth reduction of 10%, 2%, and 18% respectively. Note that the ratio of P. ponderosa to A. concolor shifted from 2.23:1 to 1.45:1 with the addition of $SO_2$.

## References

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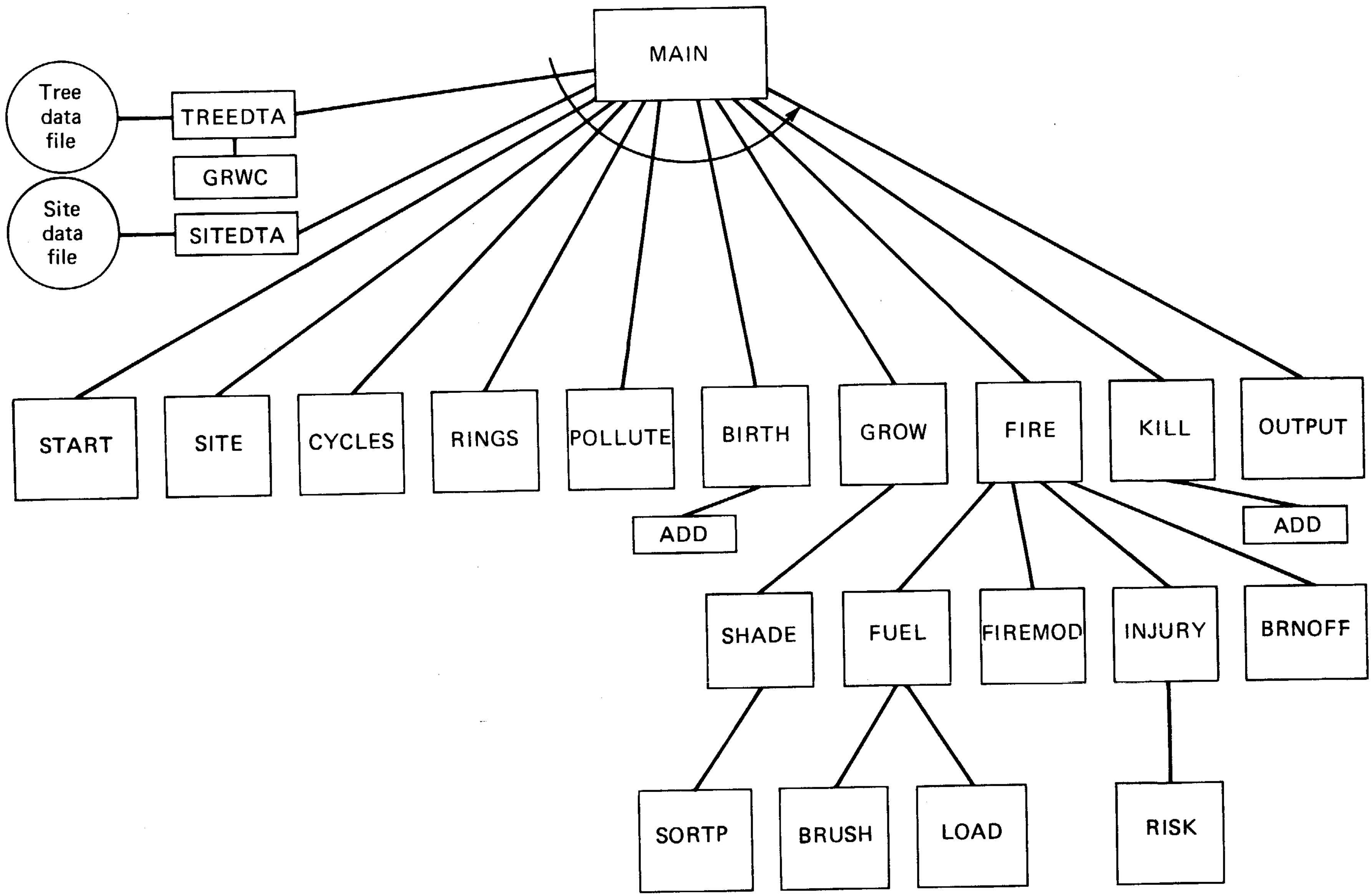
Figure Captions

Fig. 1. Structure of computer model of forest growth. Calling subroutines are located above those called.

Fig. 2. Comparison of average of basal area of 25 runs with and without fire for 500 year simulations. (a) *Pinus ponderosa*. (b) *Abies concolor*.

Fig. 3. Comparison of average of basal area of 25 runs with and without $SO_2$ pollution. $SO_2$ concentration set to induce 10% growth reduction in individual trees of *P. ponderosa*. Remaining species growth reduction scaled according to sensitivity. (a) *P. ponderosa*. (b) *A. concolor*. (c) *Pseudotsuga menziesii*.

Fig. 4. Boxplots of 500 year distributions of fractions of total basal area for data in Figure 3. Top and bottom of each box is upper and lower quartile. Runs made at 1524 m elevation with natural fire frequency.




Structure chart of succession model

Figure 1.

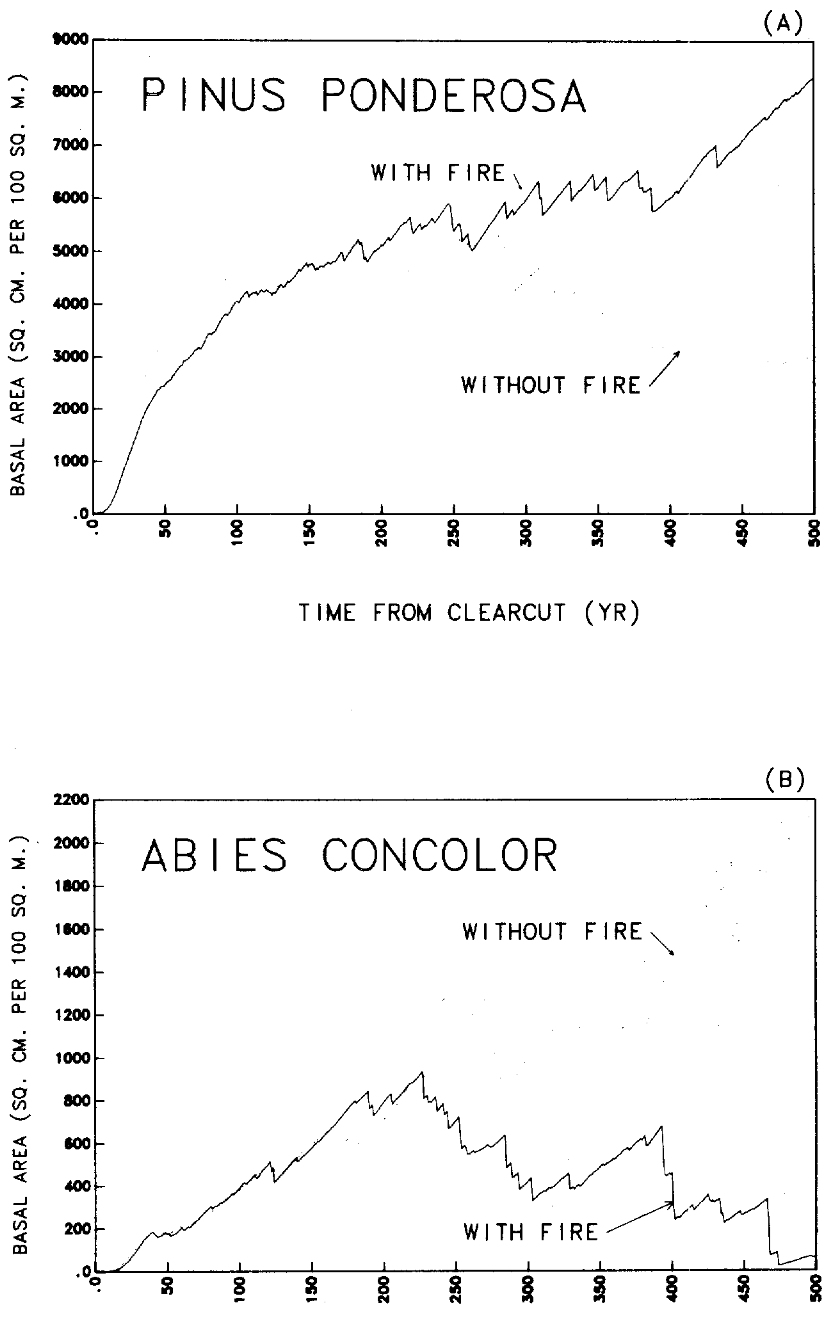

(A)
PINUS PONDEROSA
WITH FIRE
WITHOUT FIRE
BASAL AREA (SQ. CM. PER 100 SQ. M.)
TIME FROM CLEARCUT (YR)
(B)
ABIES CONCOLOR
WITHOUT FIRE
WITH FIRE
BASAL AREA (SQ. CM. PER 100 SQ. M.)
TIME FROM CLEARCUT (YR)

Figure 2.

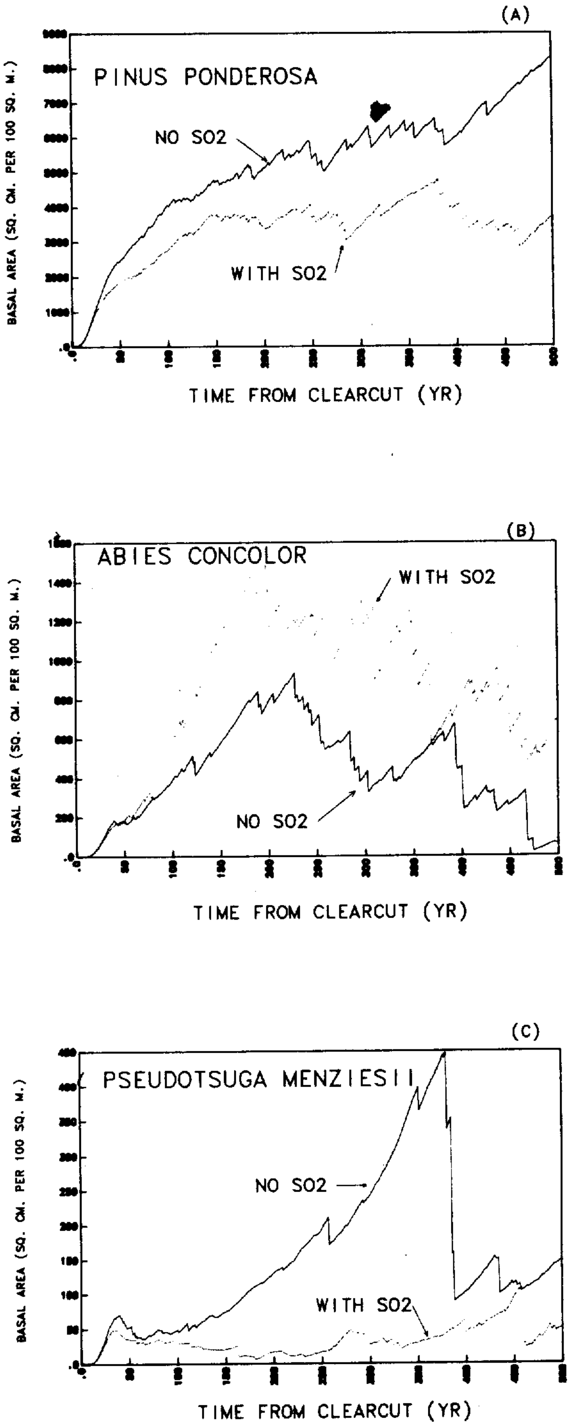
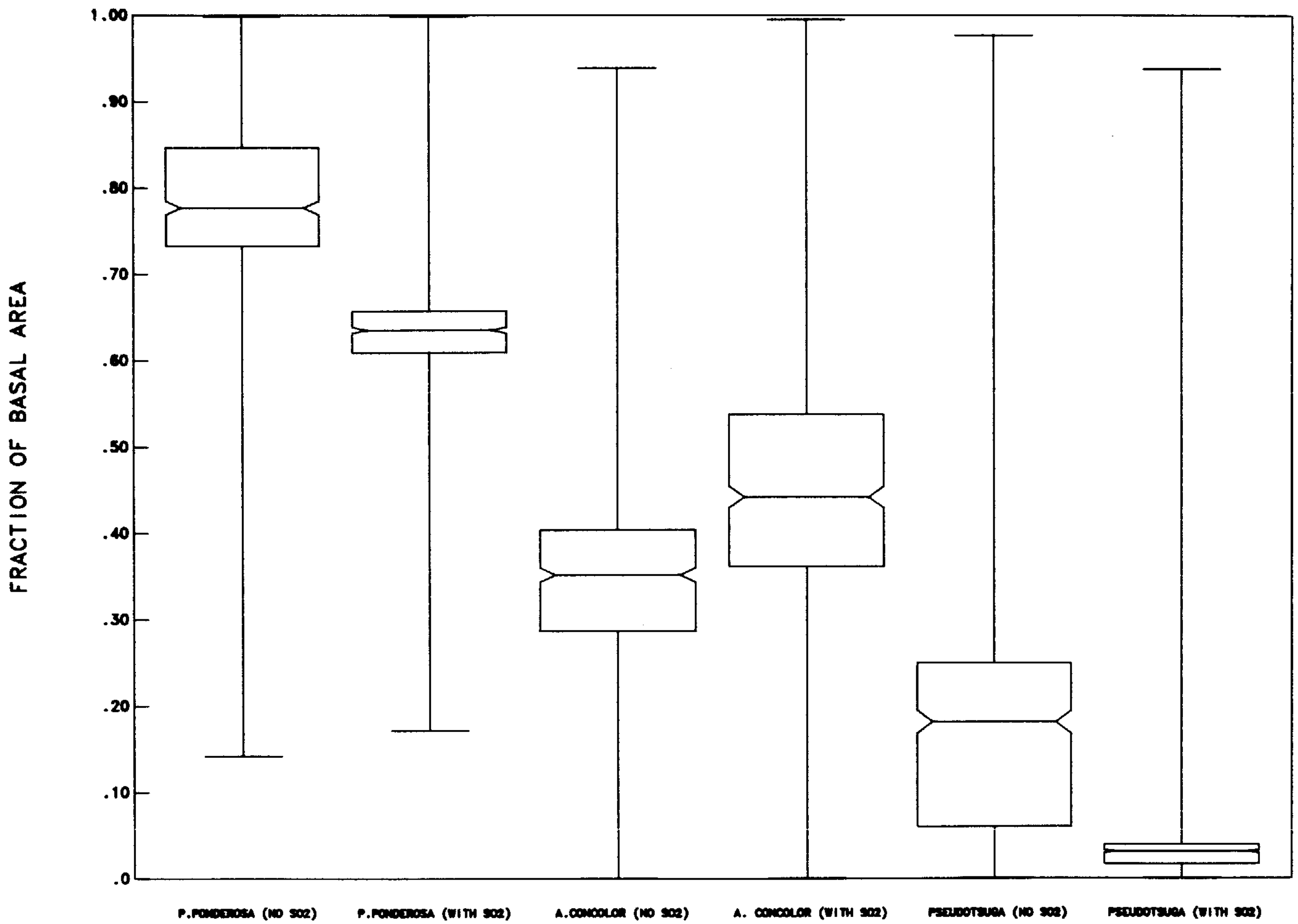

(A)
PINUS PONDEROSA
NO SO2
WITH SO2
BASAL AREA (SQ. CM. PER 100 SQ. M.)
TIME FROM CLEARCUT (YR)
(B)
ABIES CONCOLOR
WITH SO2
NO SO2
BASAL AREA (SQ. CM. PER 100 SQ. M.)
TIME FROM CLEARCUT (YR)
(C)
PSEUDOTSUGA MENZIESII
NO SO2
WITH SO2
BASAL AREA (SQ. CM. PER 100 SQ. M.)
TIME FROM CLEARCUT (YR)

Figure 3.




NON-OVERLAPPING NOTCHS INDICATE SIGNIFICANT DIFFERENCE AT APPROX 95% LEVEL

COMPARISON OF DISTRIBUTION OF FRACTION OF TOTAL BASAL AREA WITH AND WITHOUT SO2

Figure 4.